



Laser Ablation of Metal Doped Polymers with CO₂ Laser

EOARD Grant FA8655-03-1-3061

Properties of Laser Ablation Products of Delrin with CO₂ Laser

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OUTLINE

- **Who is DLR – Institute of Technical Physics (TP)?**
- **Lightcraft Research at TP**
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 - 3-D expansion**
 - Vacuum**
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- **Conclusions and proposal**



DLR - INSTITUTE OF TECHNICAL PHYSICS

German Aerospace Center



Astronautics

Traffic

Energy

Aeronautics

Institute of Technical Physics

**HEL / COIL
SSL / NLO
Active opt. Systems**

**Studies & Concepts
Akquisition & Support**



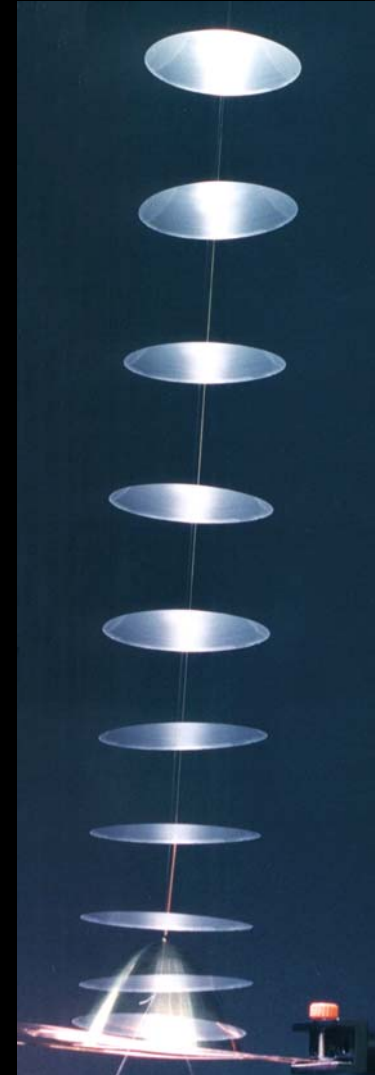
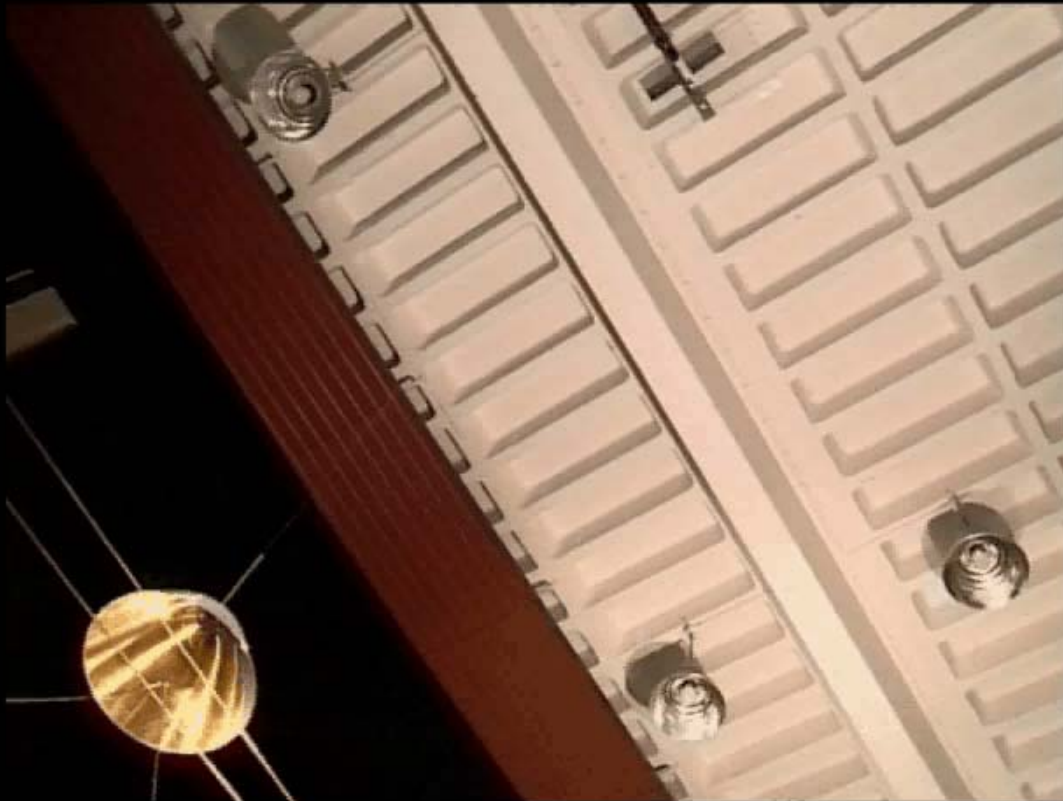
HOW IT ALL BEGAN ... (1998)



**Bicycle Headlight
Reflector**



LIGHTCRAFT FLIGHT





ACKNOWLEDGEMENT

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Dr. Franklin B. Mead Jr. and Dr. Carl W. Larson

(AFRL – Propulsion Directorate, Edwards AFB, CA)

Dr. Ingrid Wysong (EOARD - London)

(and all the others in the background)

for making our research and this visit possible.



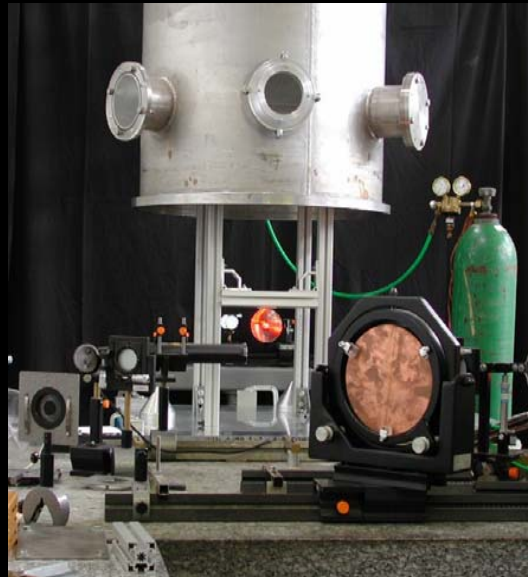
EXPERIMENTAL EQUIPMENT

Lightcraft



Parabola with
Diameter 10 cm
Focal Distance 1 cm

Vacuum Tank



Diameter 80 cm
Height 110 cm

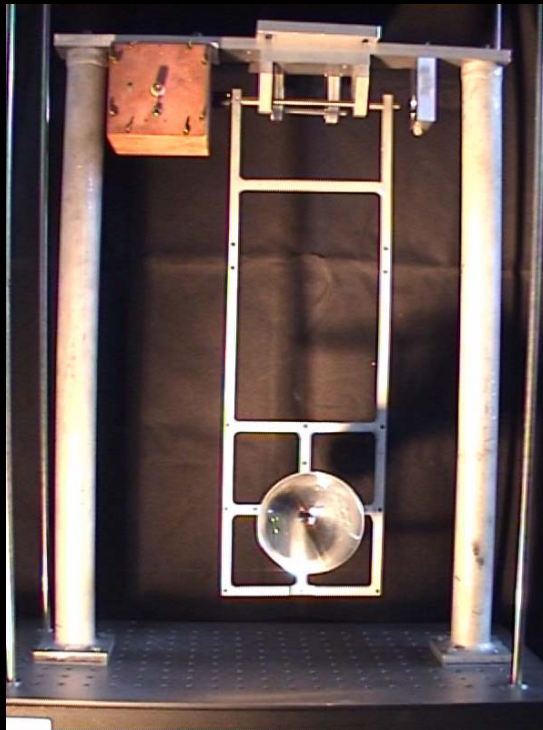
E-beam sustained CO₂ Laser



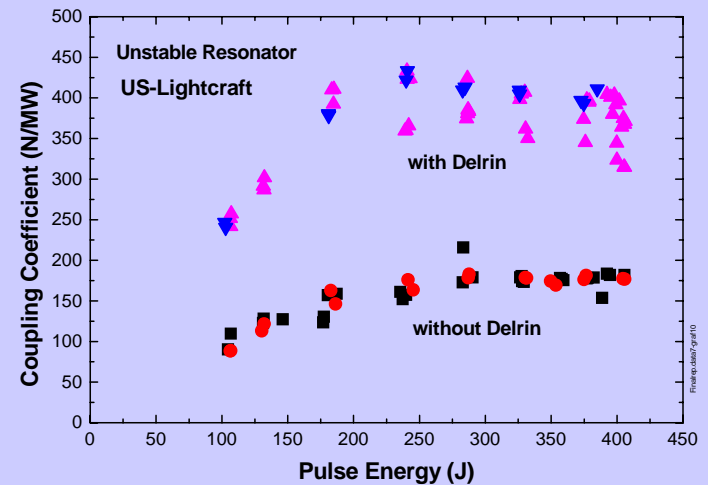
Pulse Energy ... 420 J
Repetition Rate ... 100 Hz
Wavelength 10.6 μm
Pulse Length 3 ... 12 μs



INVESTIGATIONS FOR EOARD (Phase I – 2002)

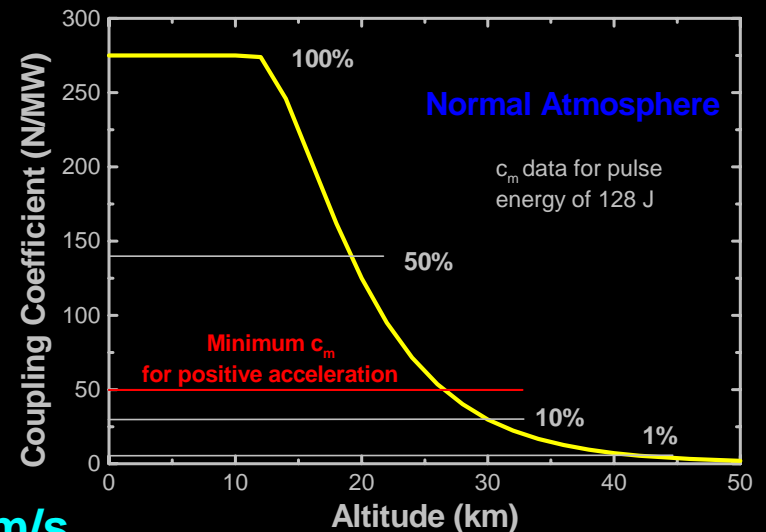
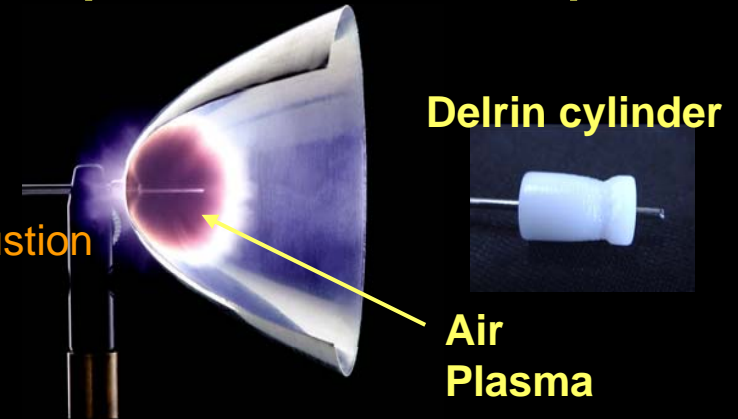
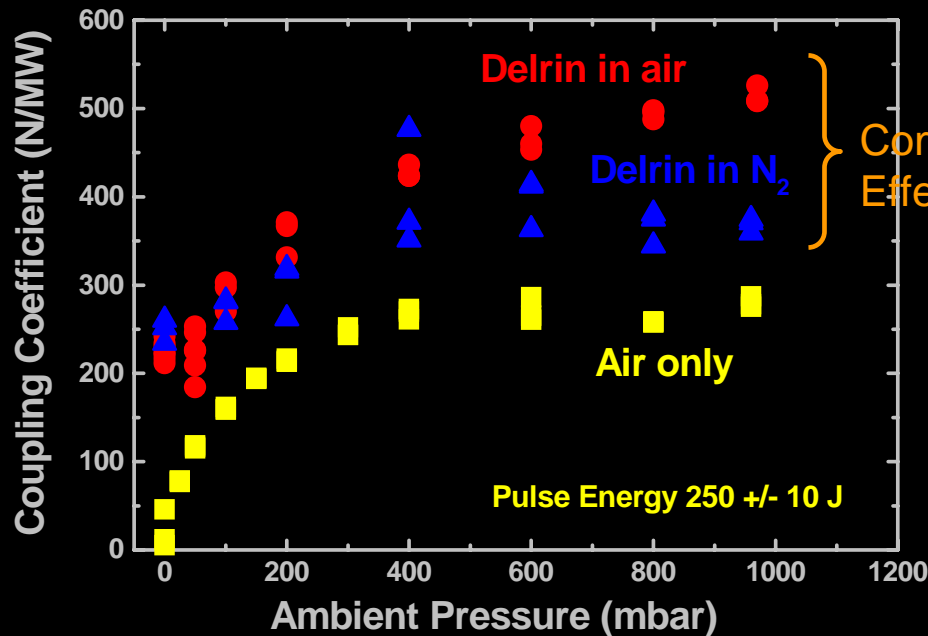


Comparison of measurement techniques and performance of US and German lightcraft





INVESTIGATIONS FOR EOARD (Phase II – 2003)

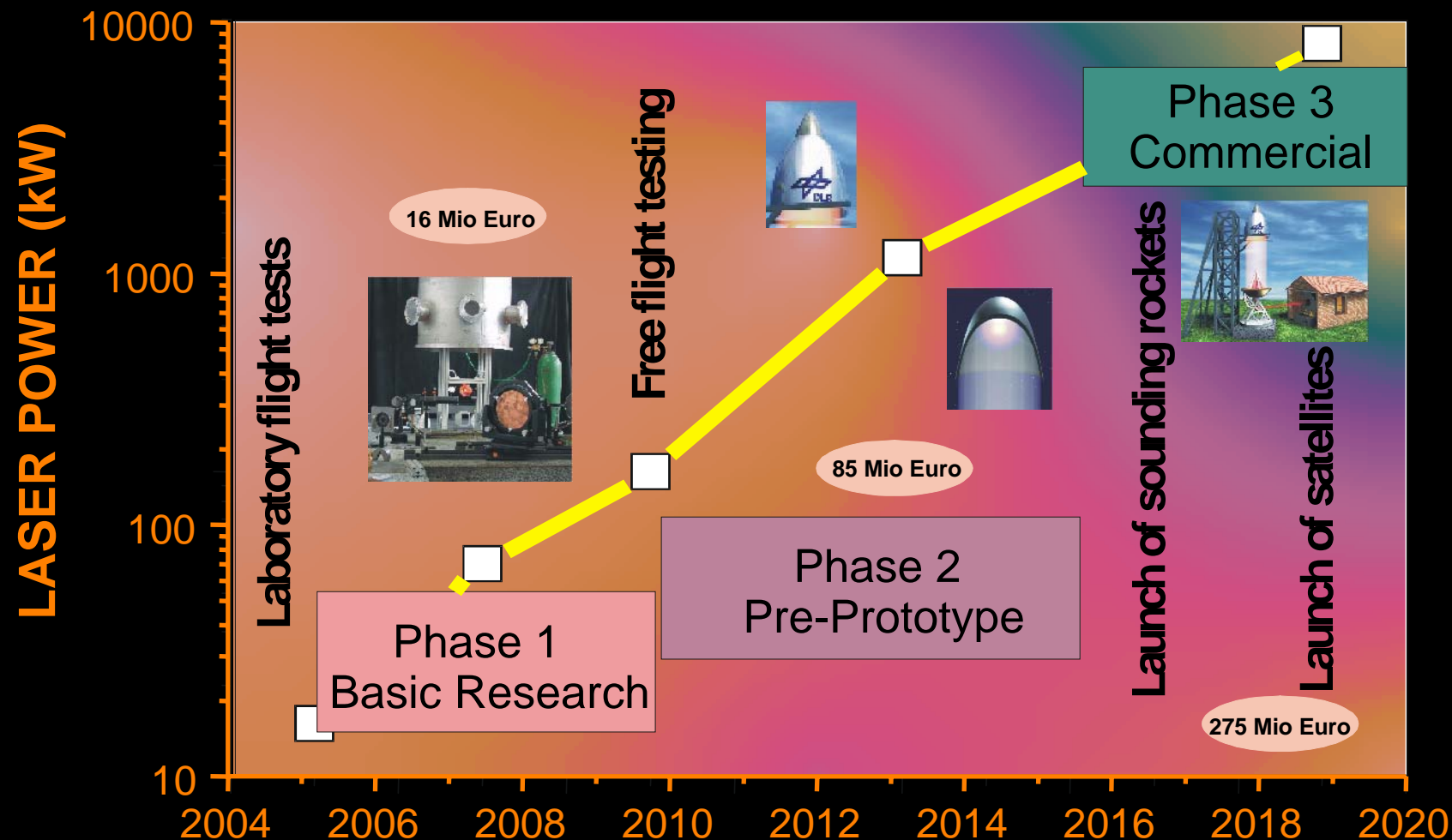


Air breathing propulsion possible to altitudes of about 30 km !

With Delrin in vacuum $v_{ex} = 2400 \pm 200$ m/s

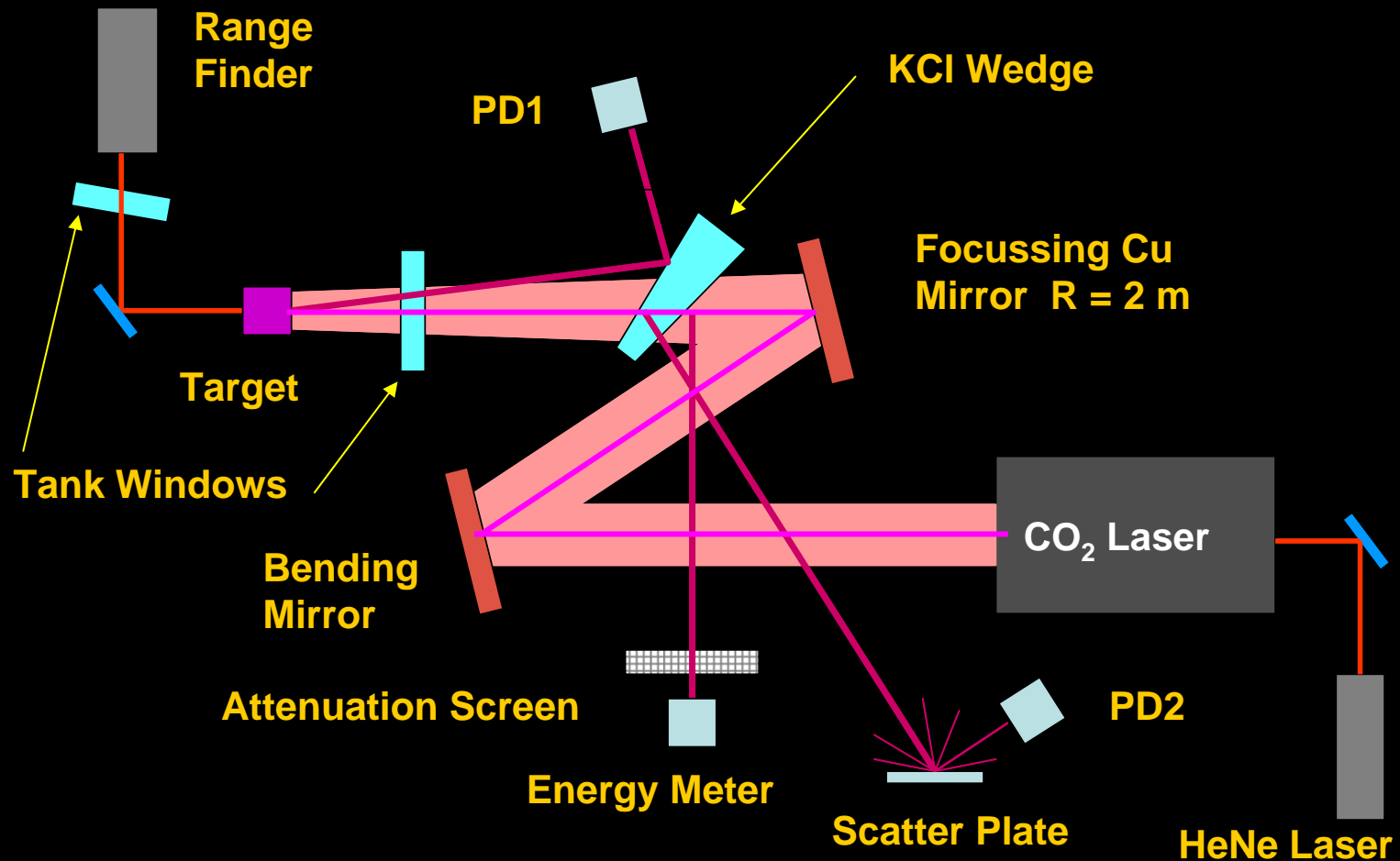


LASER LAUNCH SYSTEM DEVELOPMENT ROADMAP



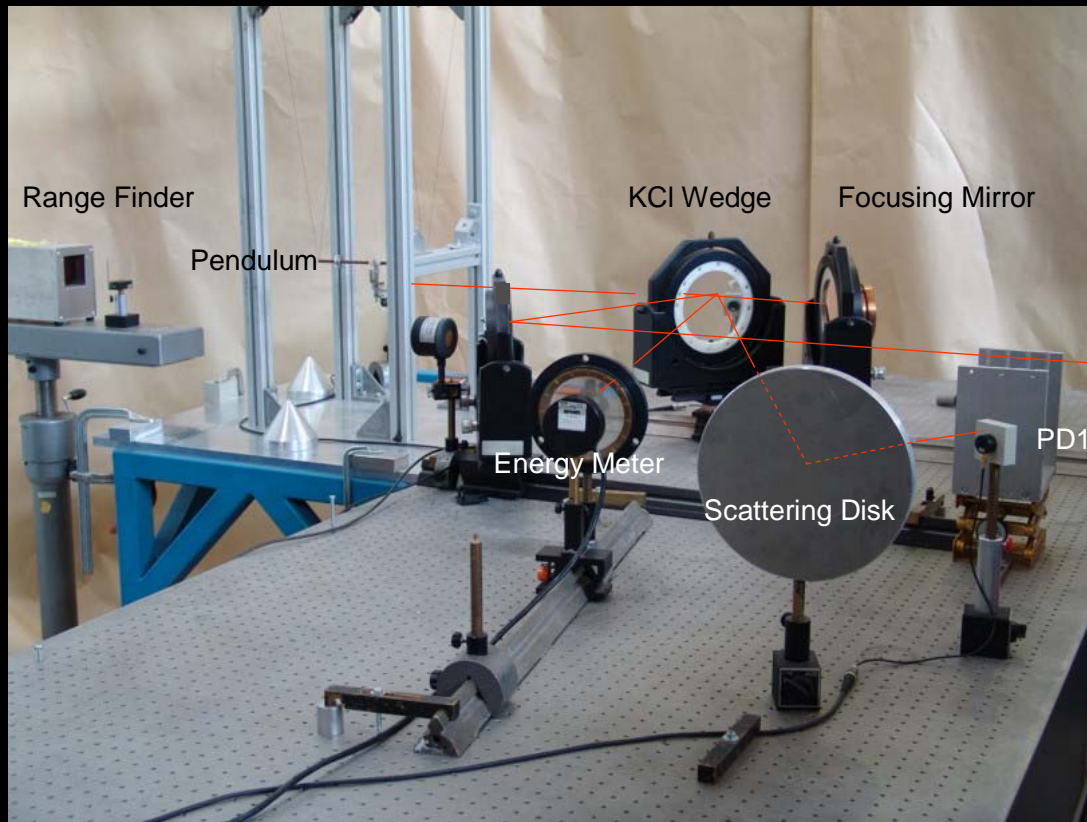


EXPERIMENTAL SETUP

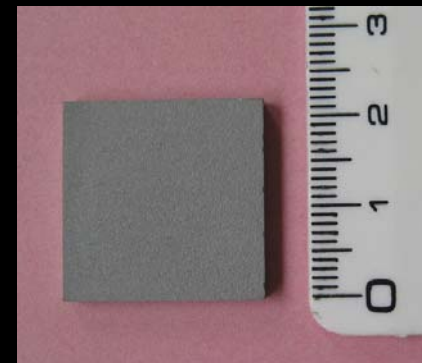
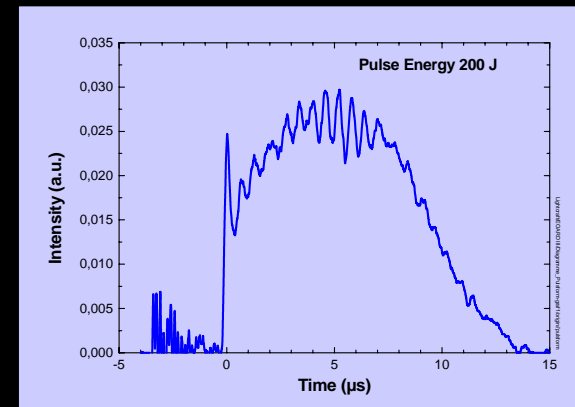




EXPERIMENTAL SETUP



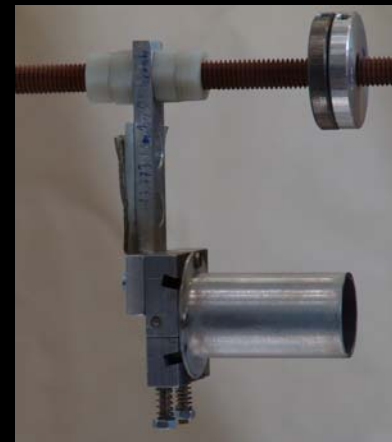
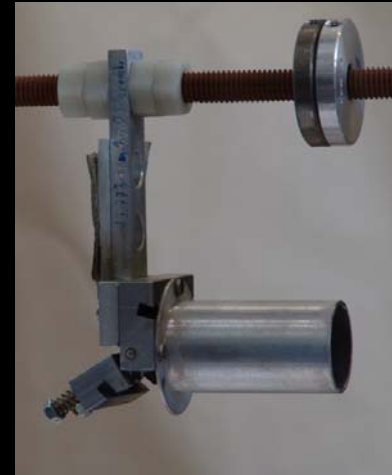
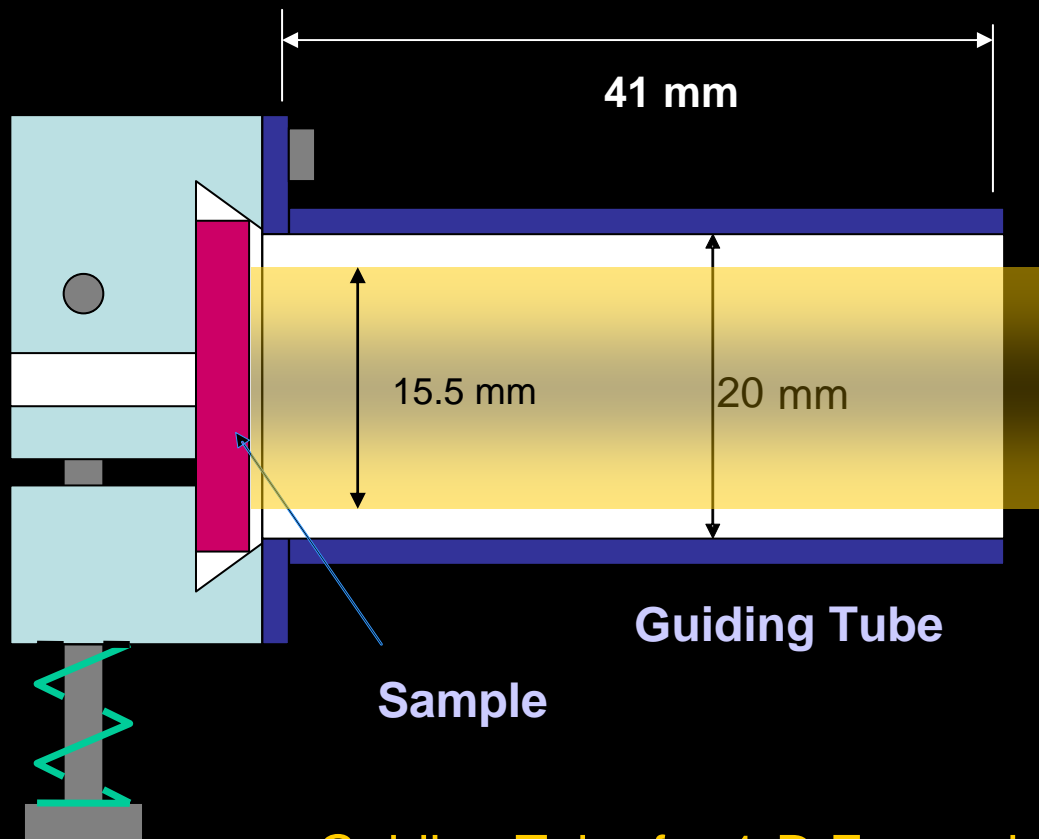
Laser Pulse Profile



Sample



SAMPLE HOLDER



Guiding Tube for 1-D Expansion



SAMPLE FORMULATIONS

POM = PolyOxyMethylene = Polyacetal = *Delrin*®

POM + Al 0, 20, 40, 60 % by wt.

Epoxy + Al 0, 3, 5, 10, 17, 30, 40, 50 % by wt.

Epoxy + Mg 0, 3, 5, 10, 17, 30, 40 % by wt.

Others: Polybutadiene + Al, POM + Fe, POM + Ti

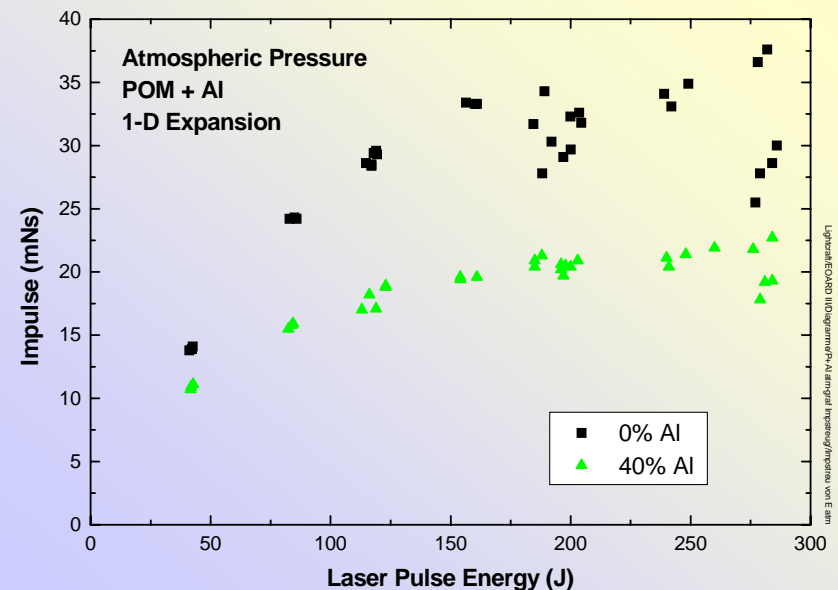
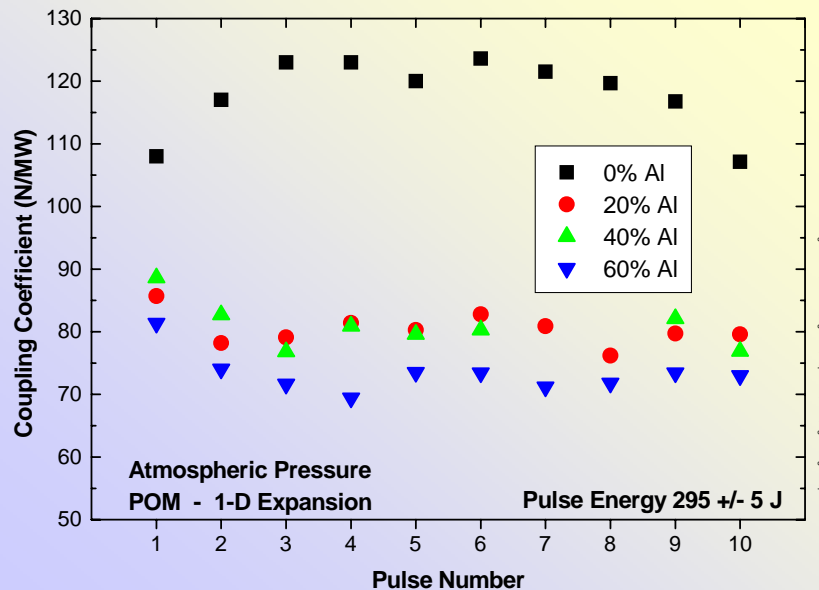


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REPRODUCIBILITY

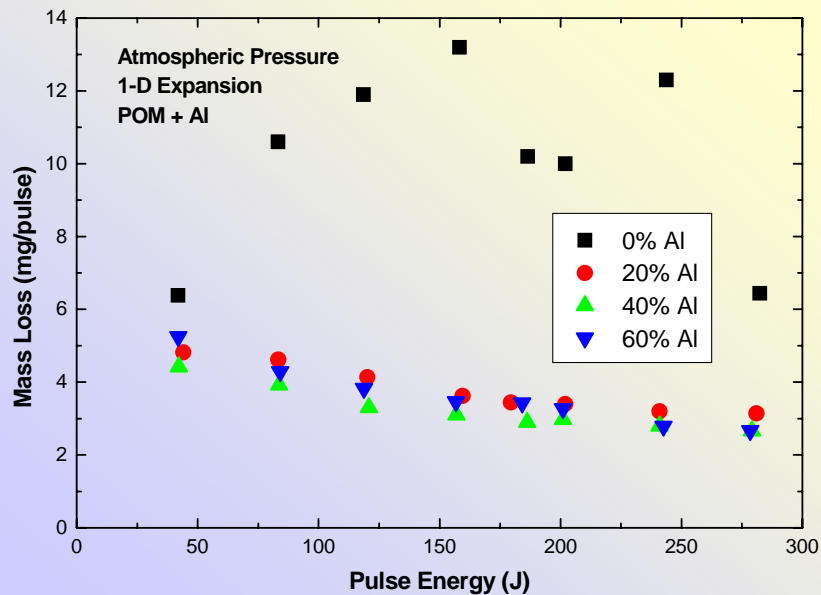


Shot to shot result on one sample

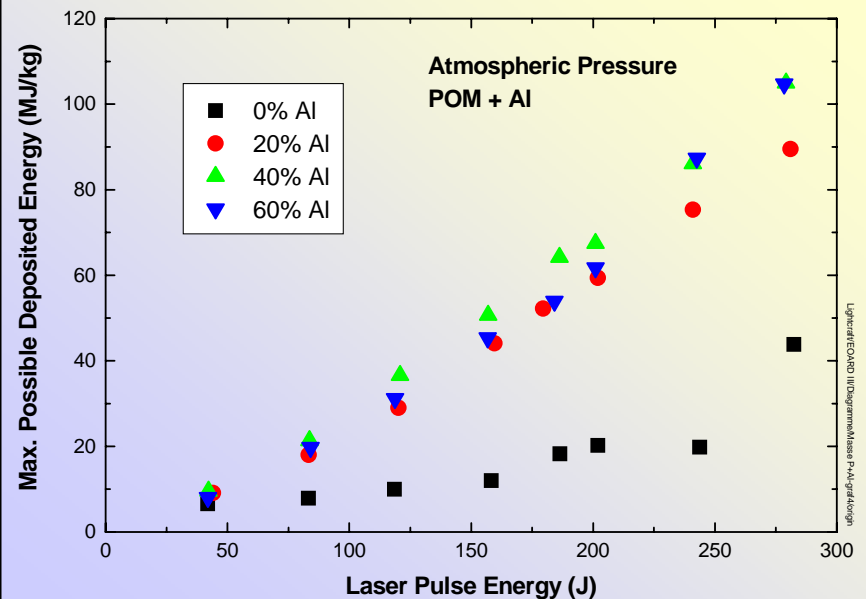
Scatter for individual shots



ABLATED MASS IN AIR



Ablated Mass vs. Pulse Energy

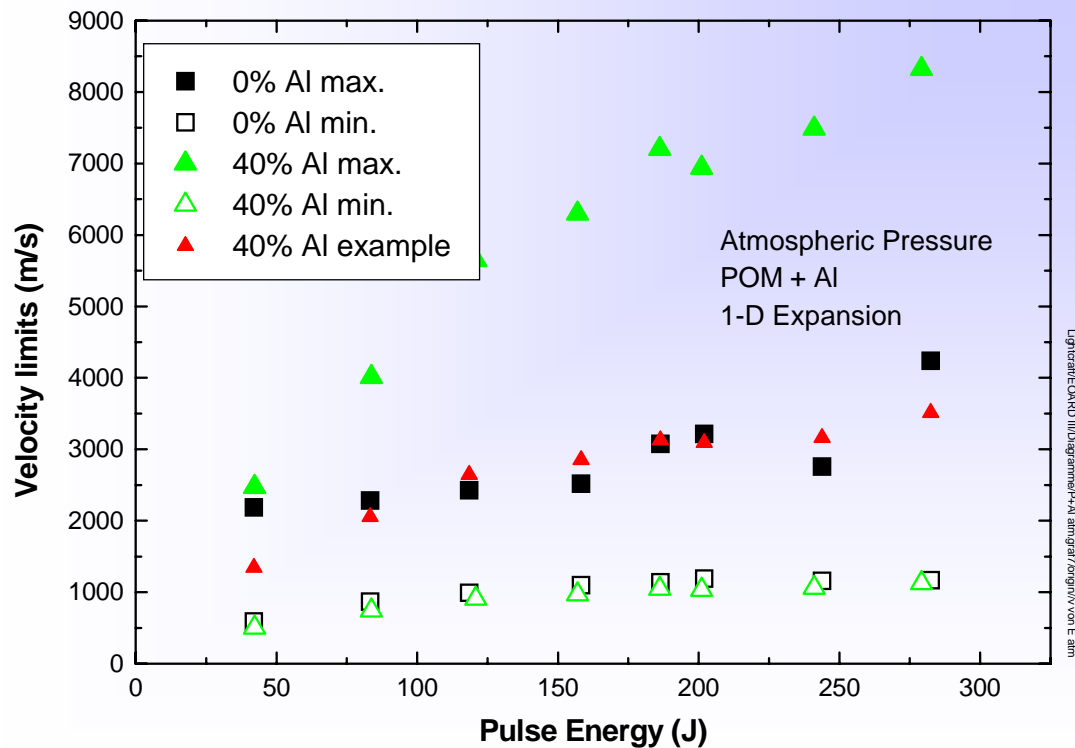


Apparent Deposited Energy

→ Upper limit



EXAMPLE: LIMITS TO THE VELOCITY



Upper Limit: 8500 m/s

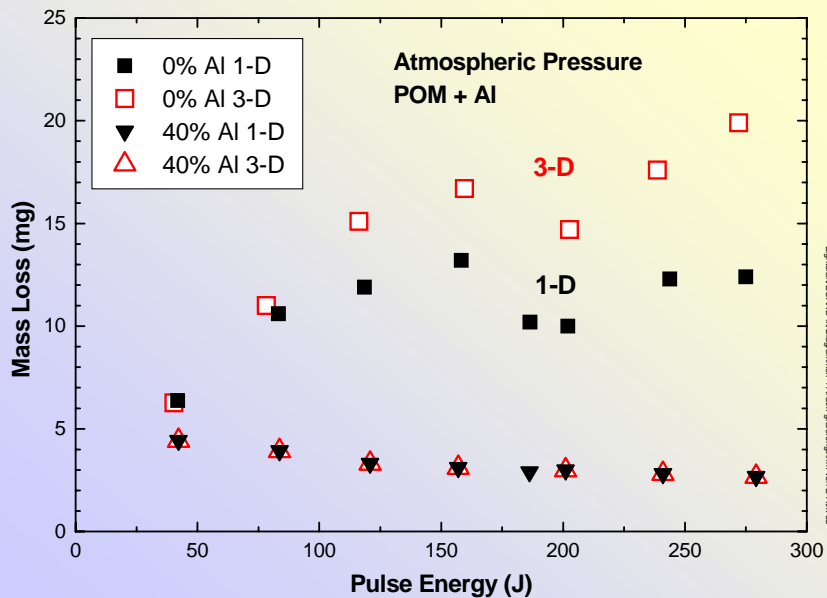
No air exhausted

Lower Limit: 1200 m/s

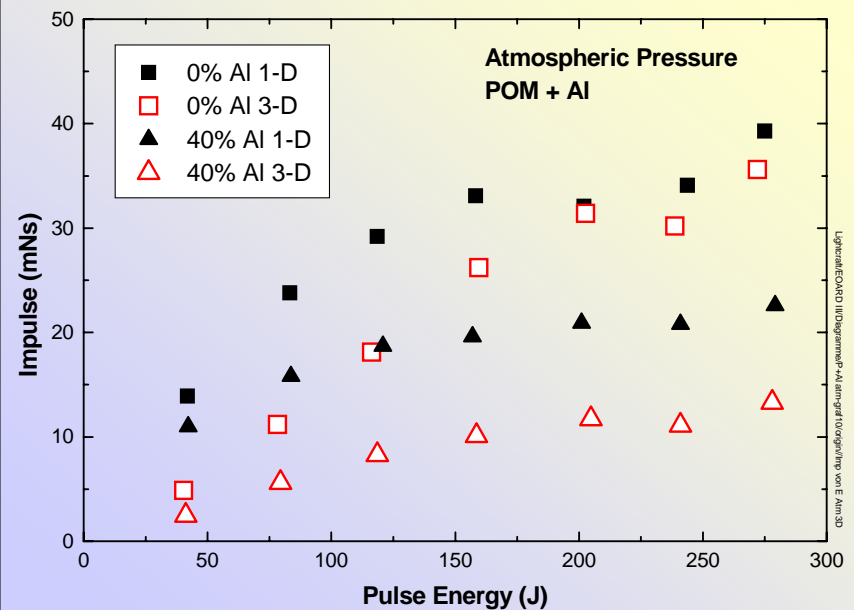
All air in tube exhausted



3-DIMENSIONAL EFFECTS



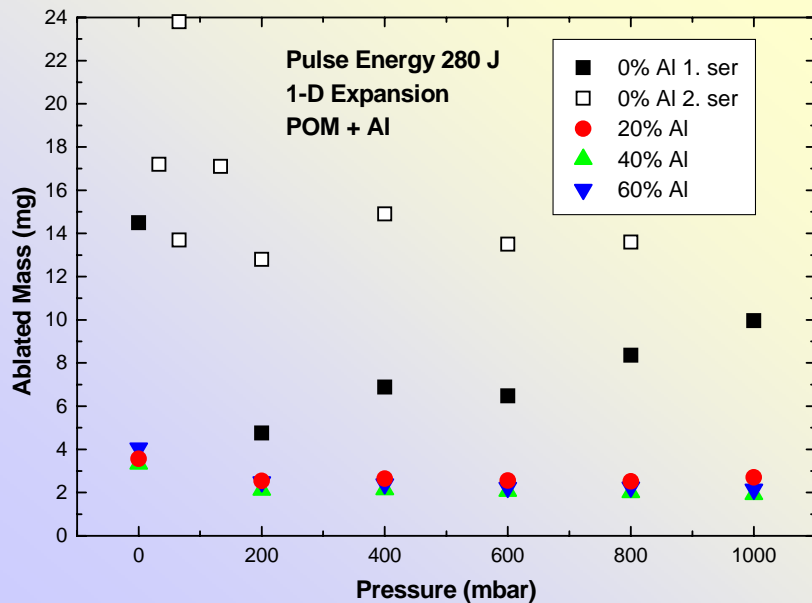
Mass Loss: 3-D vs. 1-D



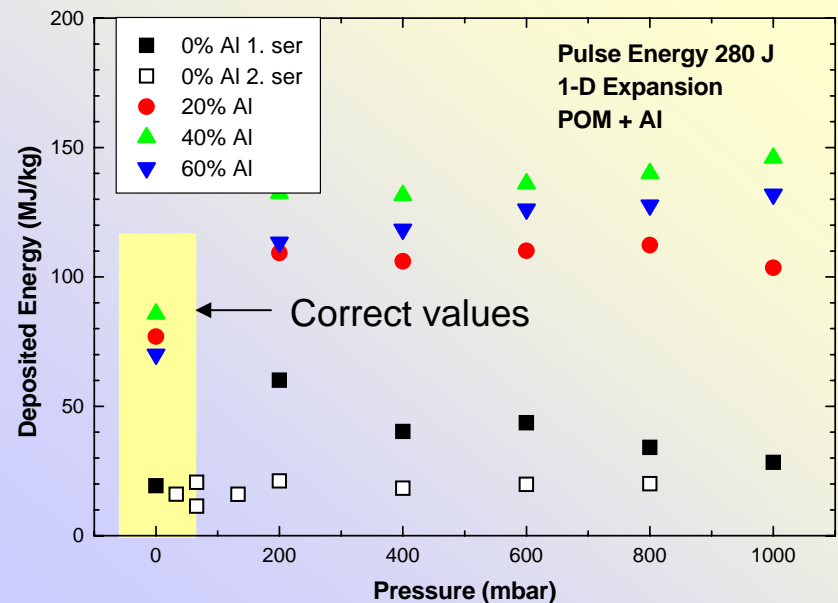
Impulse: 3-D vs. 1-D



REDUCED PRESSURE



Ablated Mass vs. Pressure

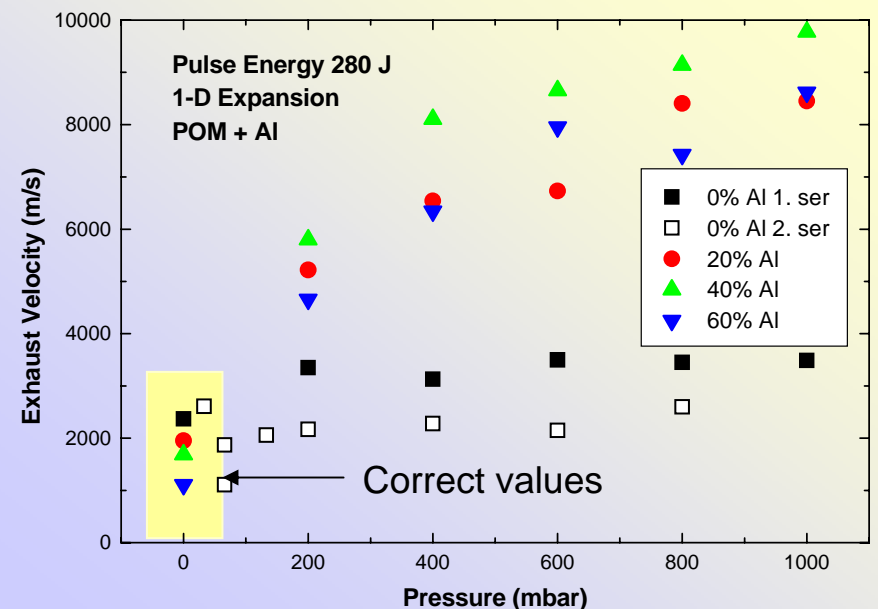
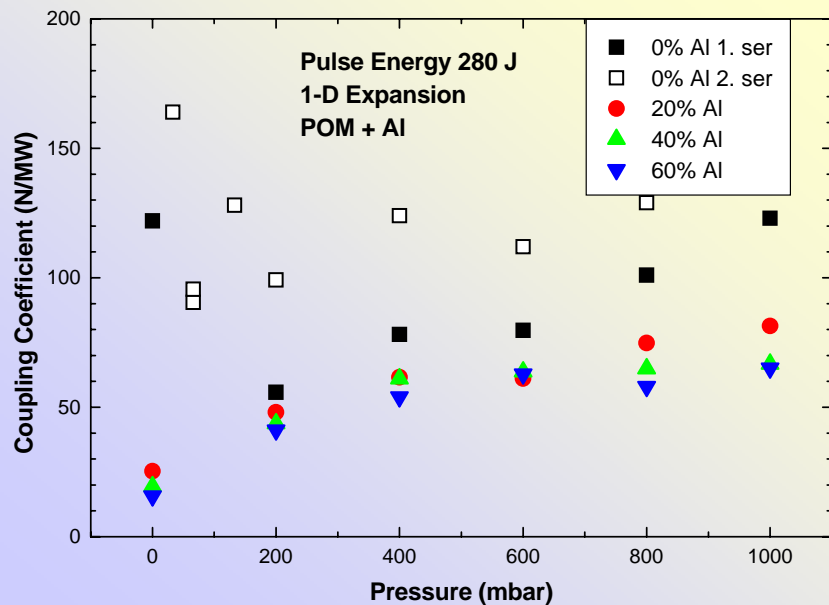


Apparent Deposited Energy

Correct only in vacuum



REDUCED PRESSURE



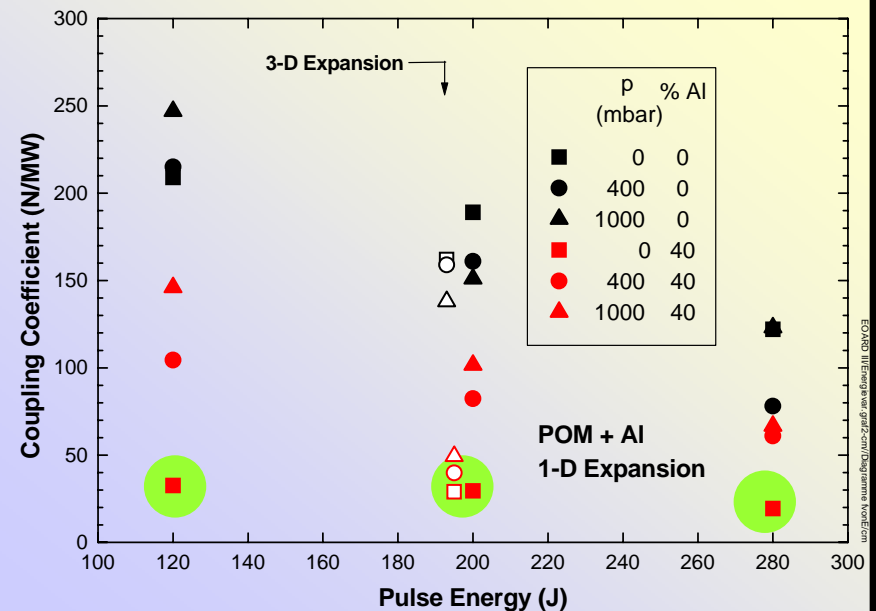
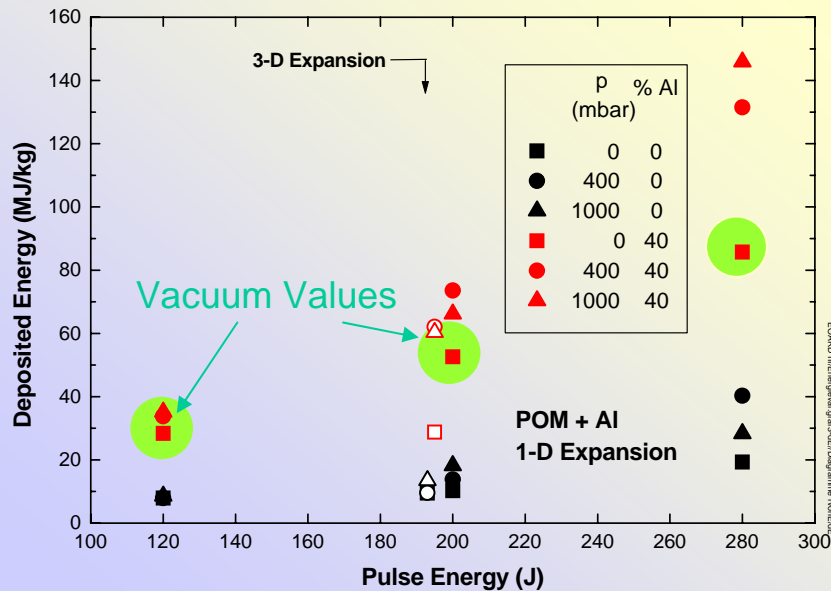
Coupling Coefficient vs. Pressure

Apparent Jet Velocity

Jet Efficiency in vacuum < 0.03



REDUCED PRESSURE



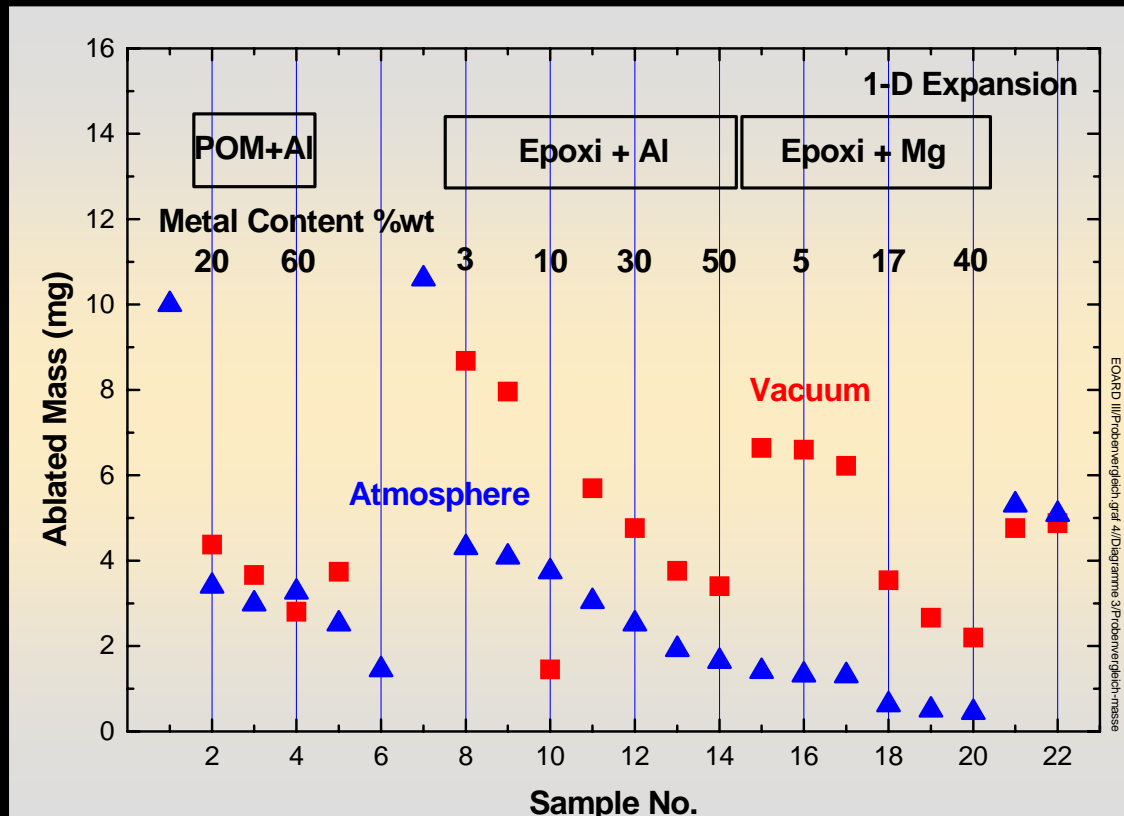
Deposited Energy vs. Pulse Energy

Coupling Coefficient vs. Pulse Energy



SAMPLE COMPARISONS - Ablated Mass

Pulse Energy
200 J

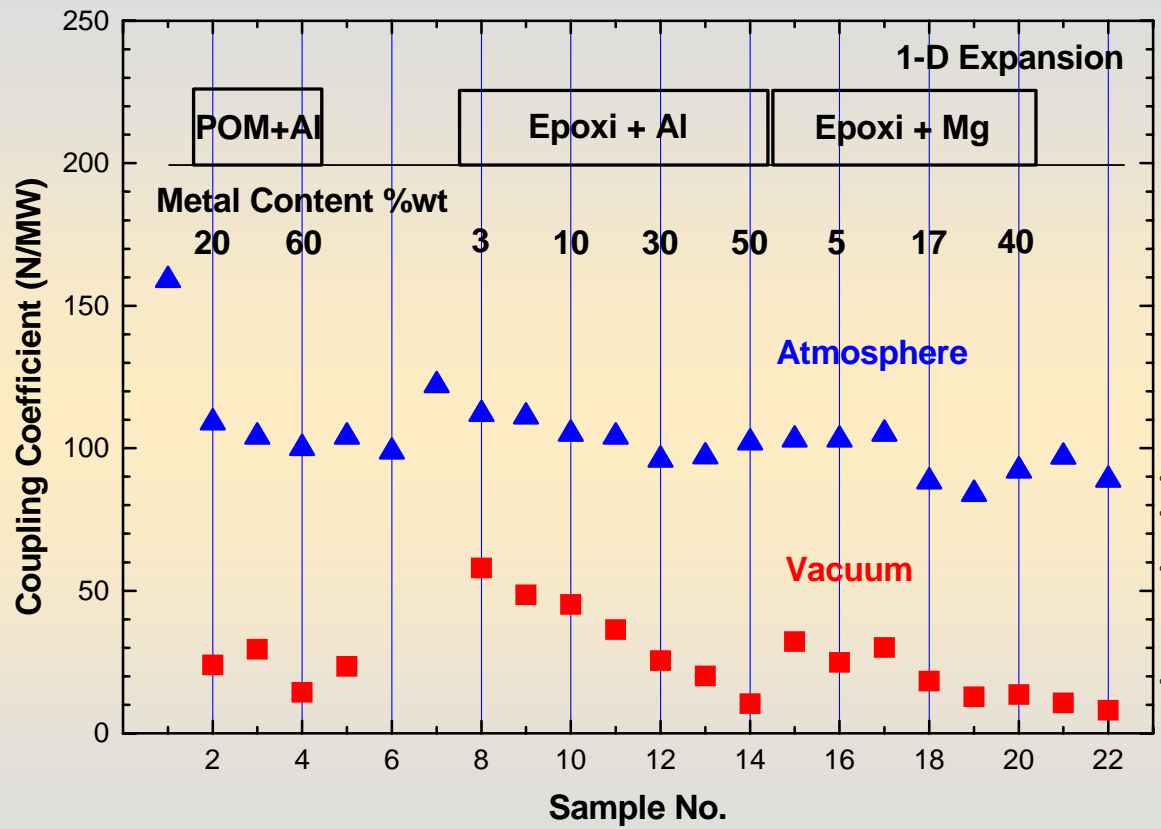


In Vacuum: Deposited Energy = $\begin{cases} 50 - 70 \text{ MJ/kg} & \text{POM} + \text{Al} \\ 20 - 60 \text{ MJ/kg} & \text{Epoxy} + \text{Al} \\ 30 - 90 \text{ MJ/kg} & \text{Epoxy} + \text{Mg} \end{cases}$



SAMPLE COMPARISONS - Coupling Coefficient

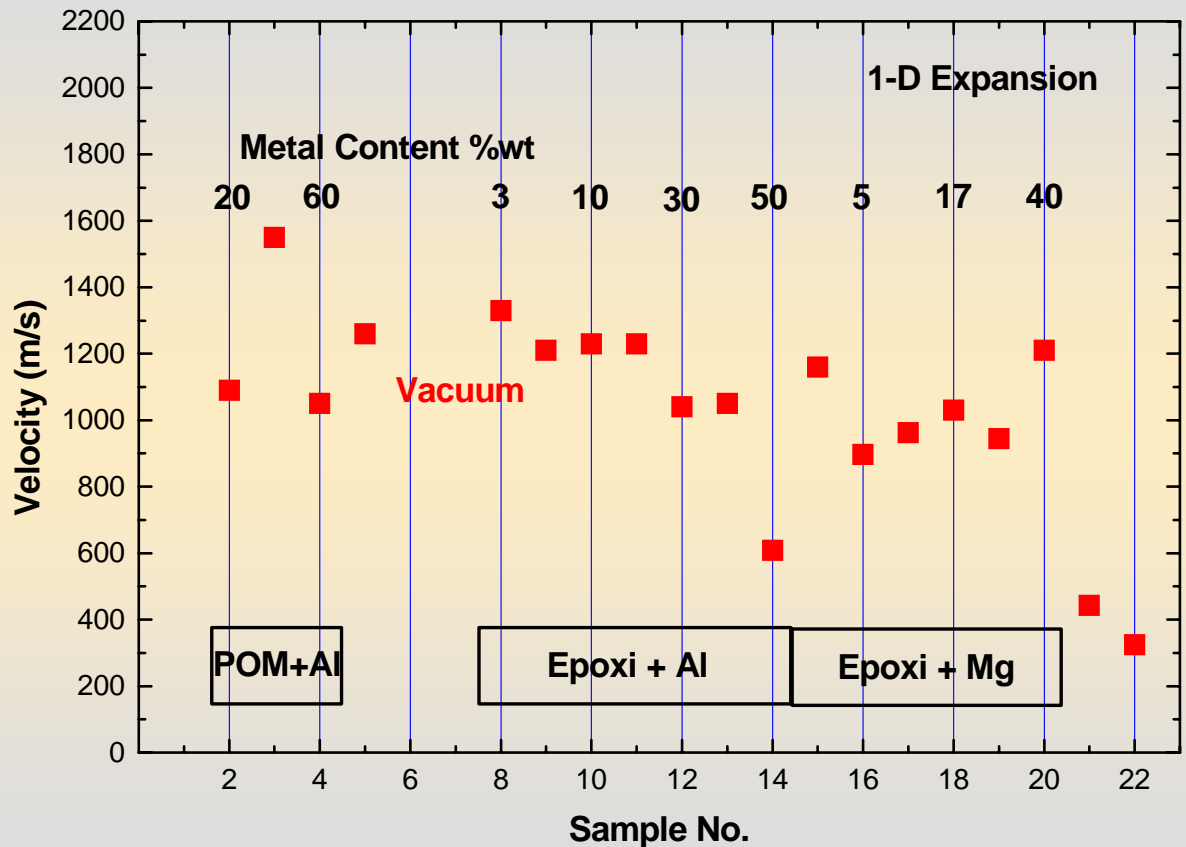
Pulse Energy
200 J





SAMPLE COMPARISONS - Jet Velocity

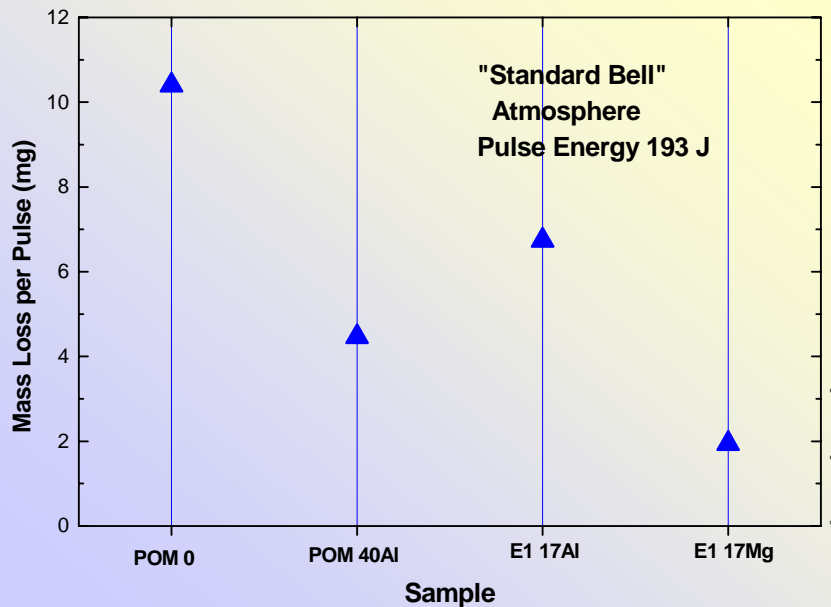
Pulse Energy
200 J



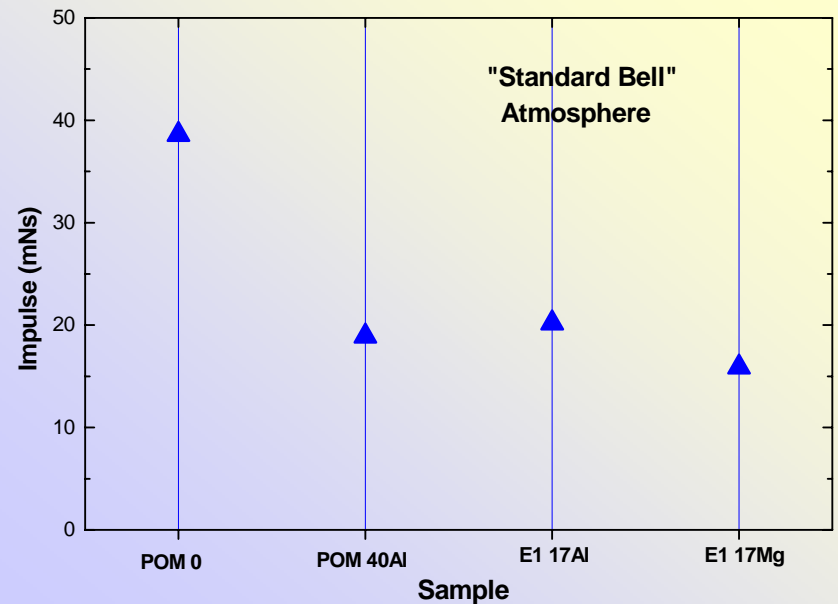
$\eta < 0.03$



COMPARISON WITH LIGHT CONCENTRATING STRUCTURE ("BELL NOZZLE") IN AIR – 200 J



20 ... 50 MJ/kg 100 MJ/kg
Apparent Deposited Energy



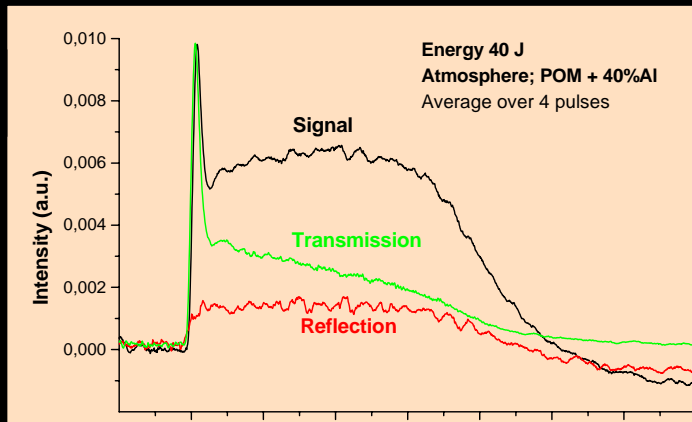
200 N/MW 100 N/MW
Coupling Coefficient



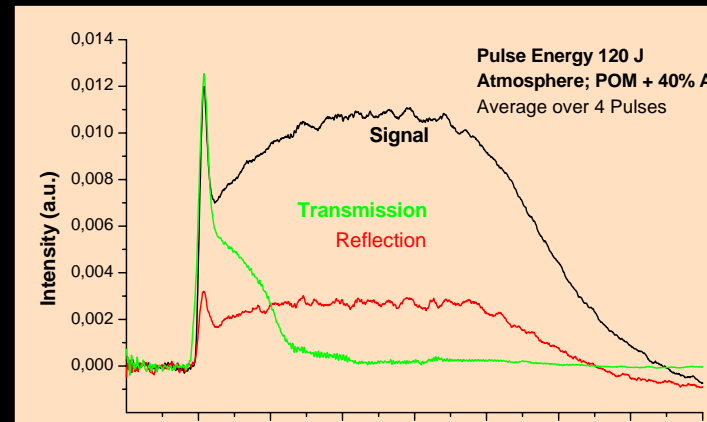
POWER PROFILES

POM + 40 % Al in air

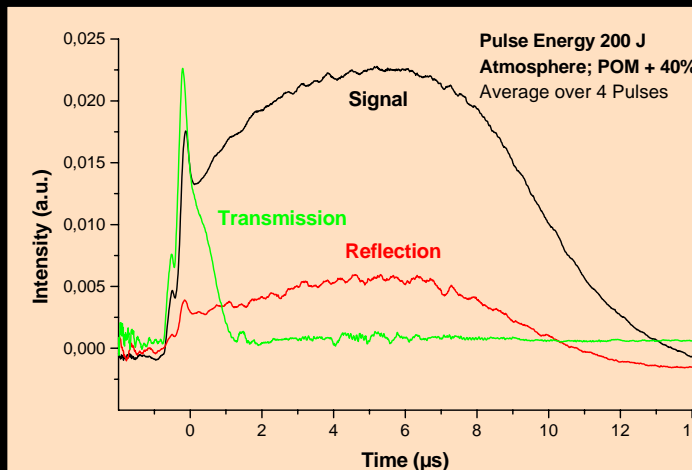
40 J



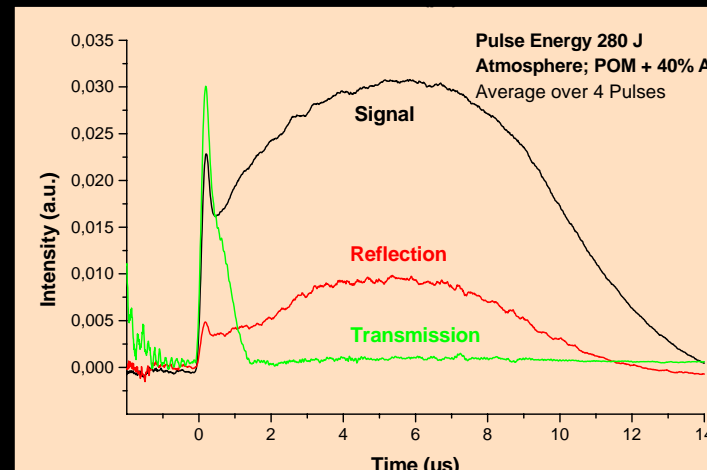
120 J



200 J



280 J





OUTLINE

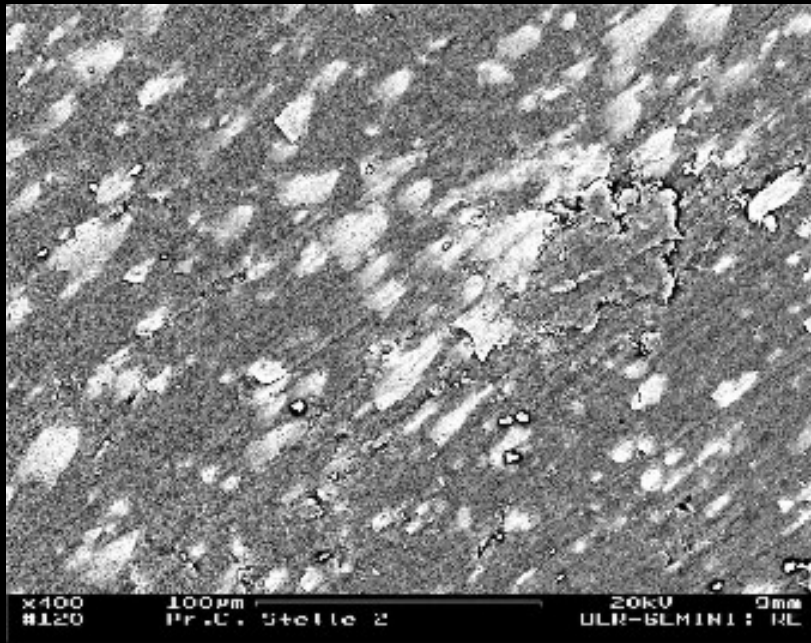
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ELECTRON MICROSCOPE PICTURES

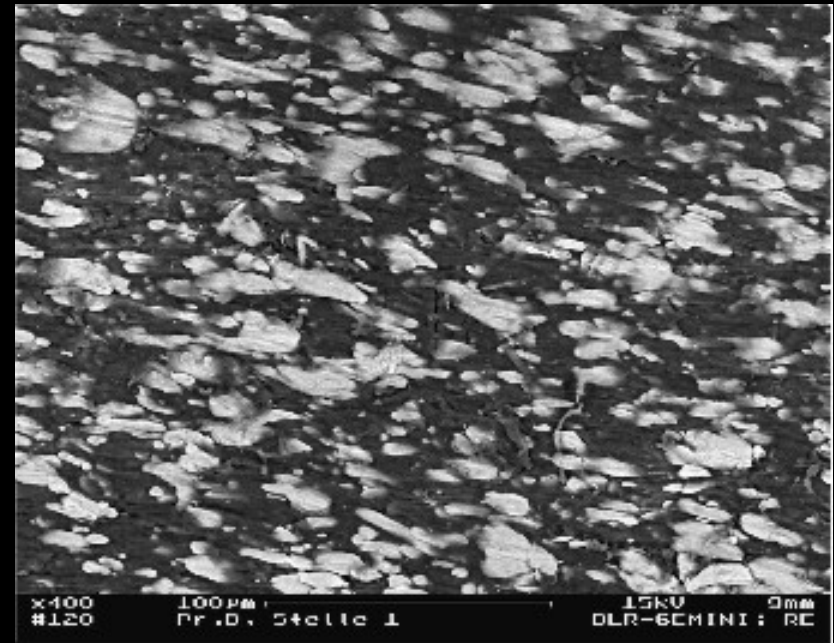
Before Laser Irradiation

RE-Mode



POM + 20 % Al

400x



POM + 40 % Al

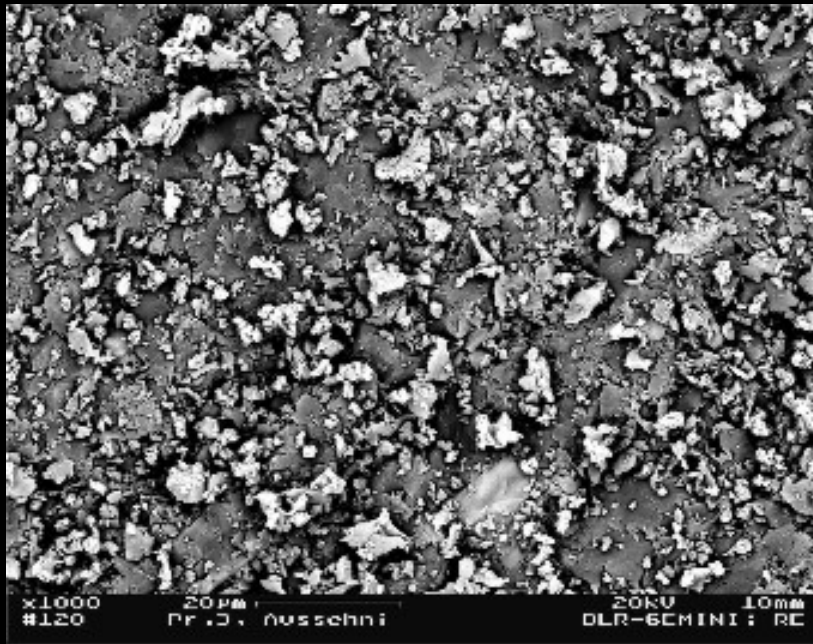
400x



ELECTRON MICROSCOPE PICTURES

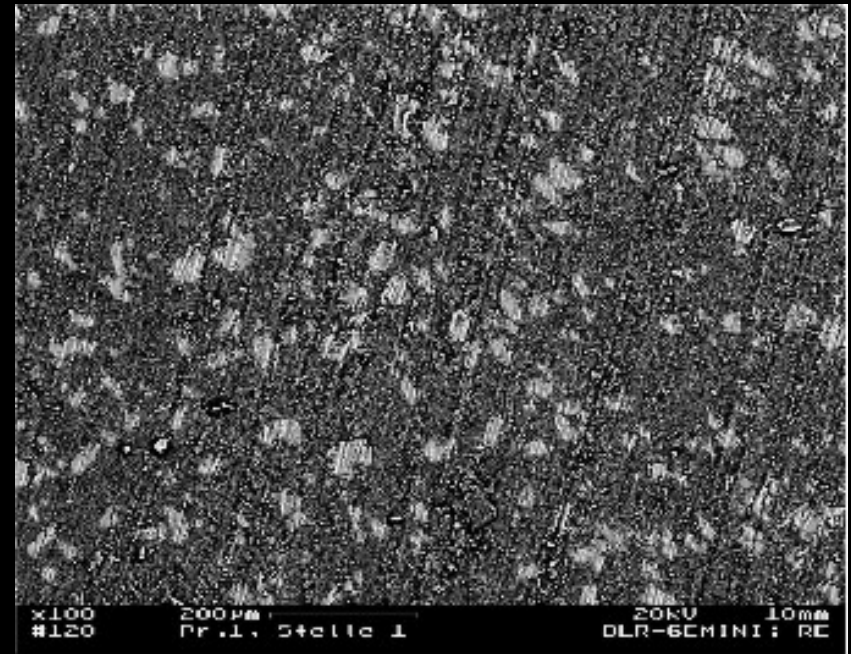
Before Laser Irradiation

RE-Mode



Epoxy + 17% Al

1000x



Epoxy + 17% Mg

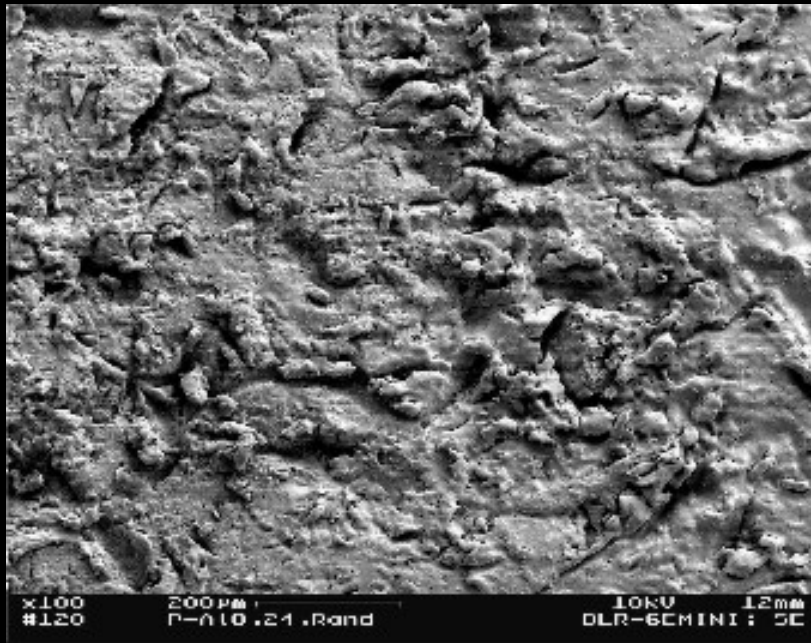
100x



ELECTRON MICROSCOPE PICTURES

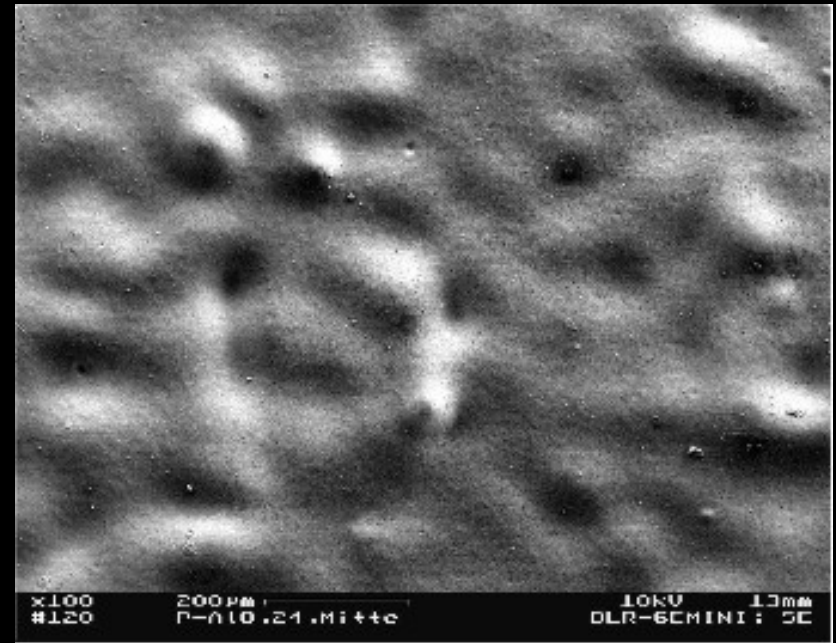
After Laser Irradiation

SE-Mode



POM – edge

100x



POM - center

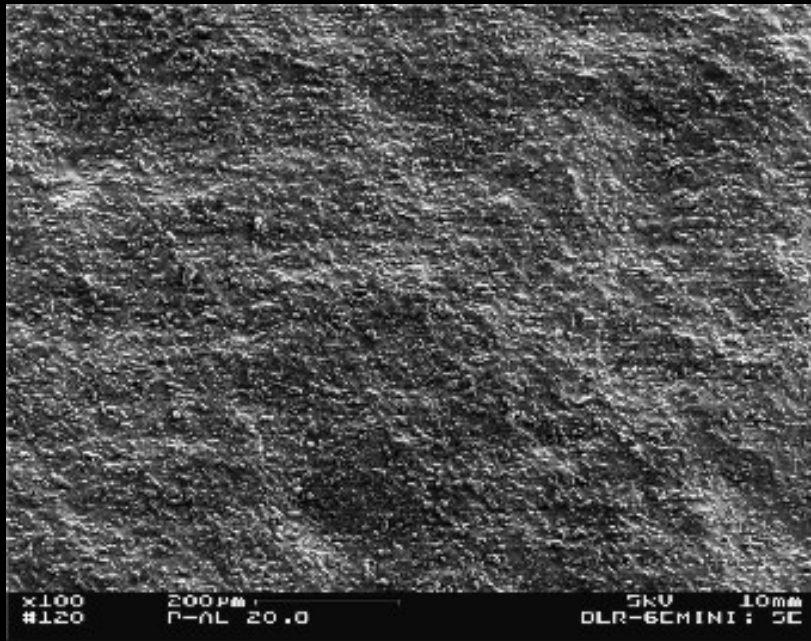
100x



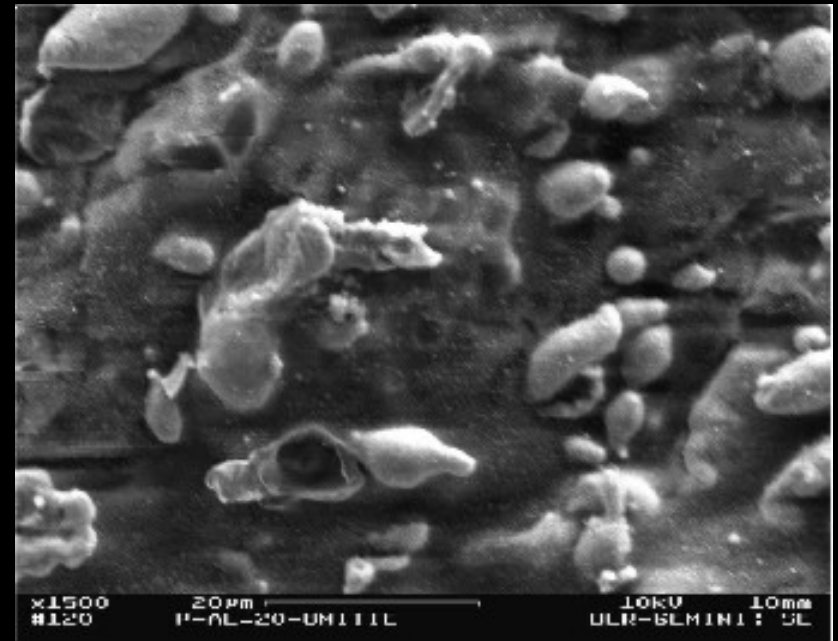
ELECTRON MICROSCOPE PICTURES

After Laser Irradiation

SE-Mode 200 J vacuum



POM + 20 % Al - center 100x



POM + 40 % Al

1500x

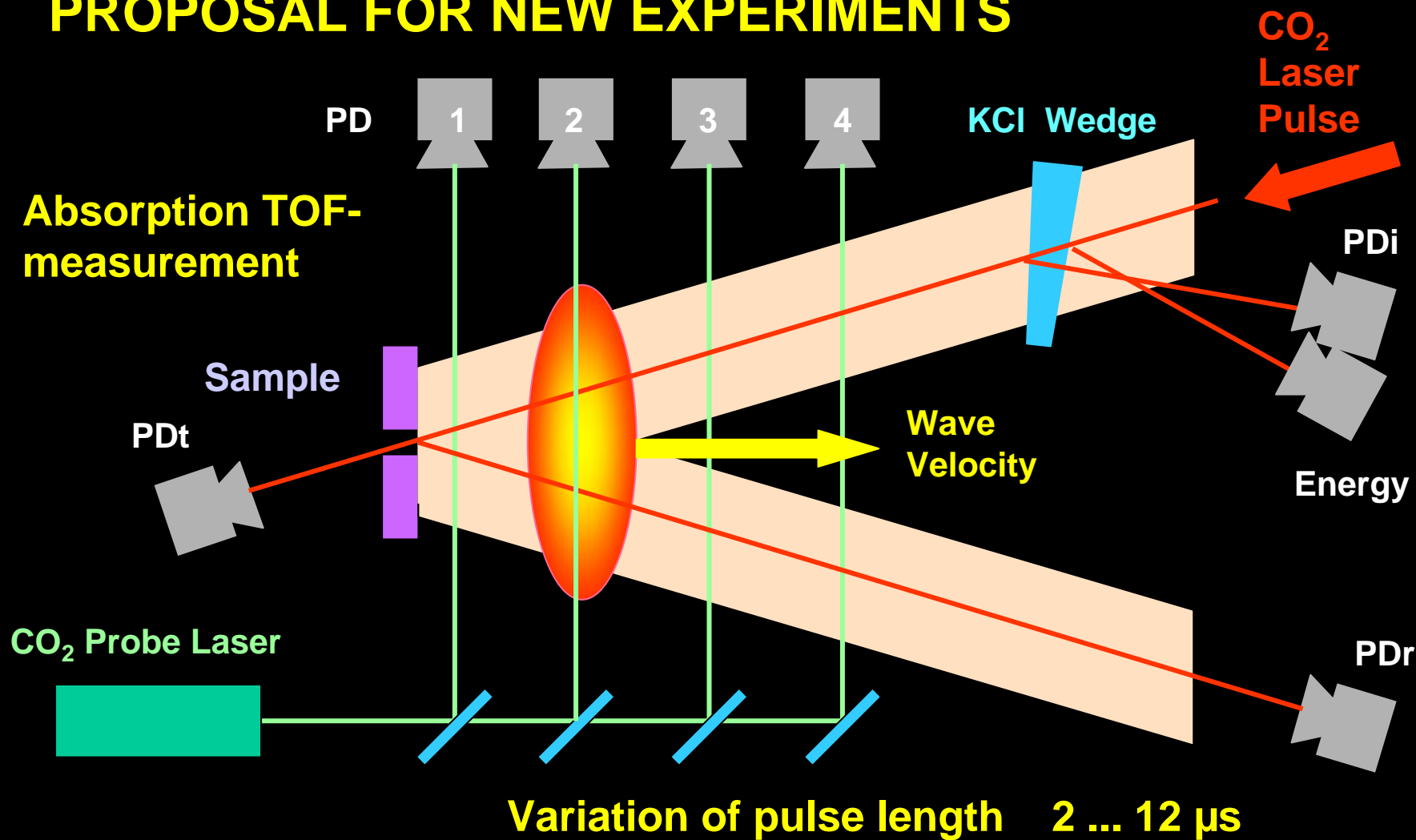


CONCLUSIONS

- Goals for $I_s = 800$ s not met
- In air → accelerated air fraction unknown
→ all related values are wrong
- In vacuum → deposited energy goes up with increasing metal fraction, but coupling coefficient decreases
- Strong evidence for large energy loss in a decoupled laser absorption wave
- Nature and characteristics of absorption wave need investigation
- Can shorter pulse lengths help prevent decoupling?



PROPOSAL FOR NEW EXPERIMENTS





POM after laser irradiation 3000x